

Development of Weld Inspection of the Ares I Crew Launch Vehicle Upper Stage


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ABSTRACT

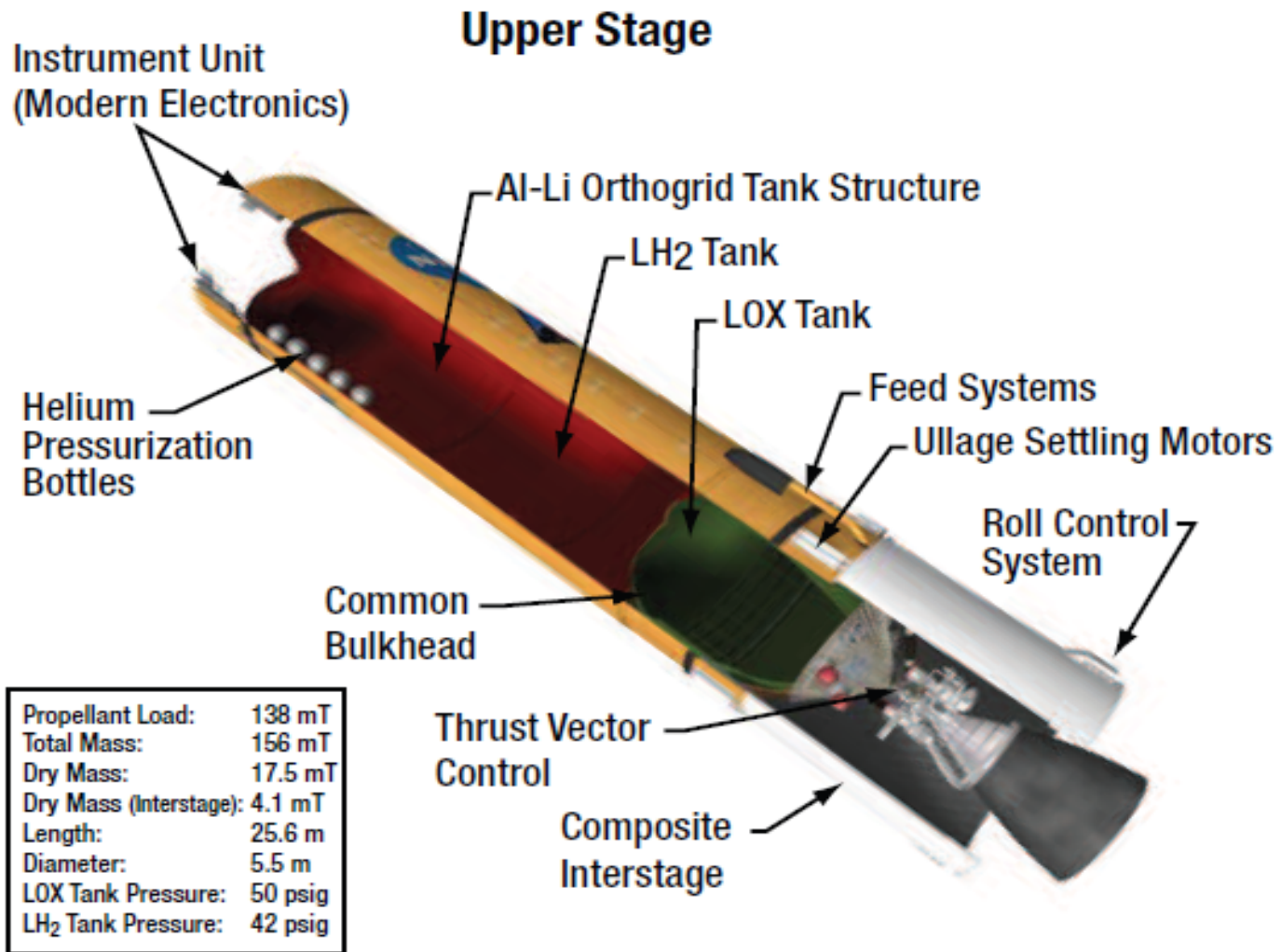
NASA is designing a new crewed launch vehicle called Ares I to replace the Space Shuttle after its scheduled retirement in 2010. This new launch vehicle will build on the Shuttle technology in many ways including using a first stage based upon the Space Shuttle Solid Rocket Booster, advanced aluminum alloys for the second stage tanks, and friction stir welding to assemble the second stage. Friction stir welding uses a spinning pin that is inserted in the joint between two panels that are to be welded. The pin mechanically mixes the metal together below the melting temperature to form the weld. Friction stir welding allows high strength joints in metals that would otherwise lose much of their strength as they are melted during the fusion welding process. One significant change from the Space Shuttle that impacts NDE is the implementation of self-reacting friction stir welding for non-linear welds on the primary metallic structure. The self-reacting technique differs from the conventional technique because the load of the pin tool pressing down on the metal being joined is reacted by a nut on the end of the tool rather than an anvil behind the part. No spacecraft has ever flown with a self-reacting friction stir weld, so this is a major advancement in the manufacturing process, bringing with it a whole new set of challenges for NDE to overcome. The metal microstructure and possible defects are different from other weld processes. Friction plug welds will be used to close out the hole remaining in the radial welds when friction stir welded. This plug welding also has unique challenges in inspection. The current state of development of these inspections will be presented, along with other information pertinent to NDE of the Ares I.

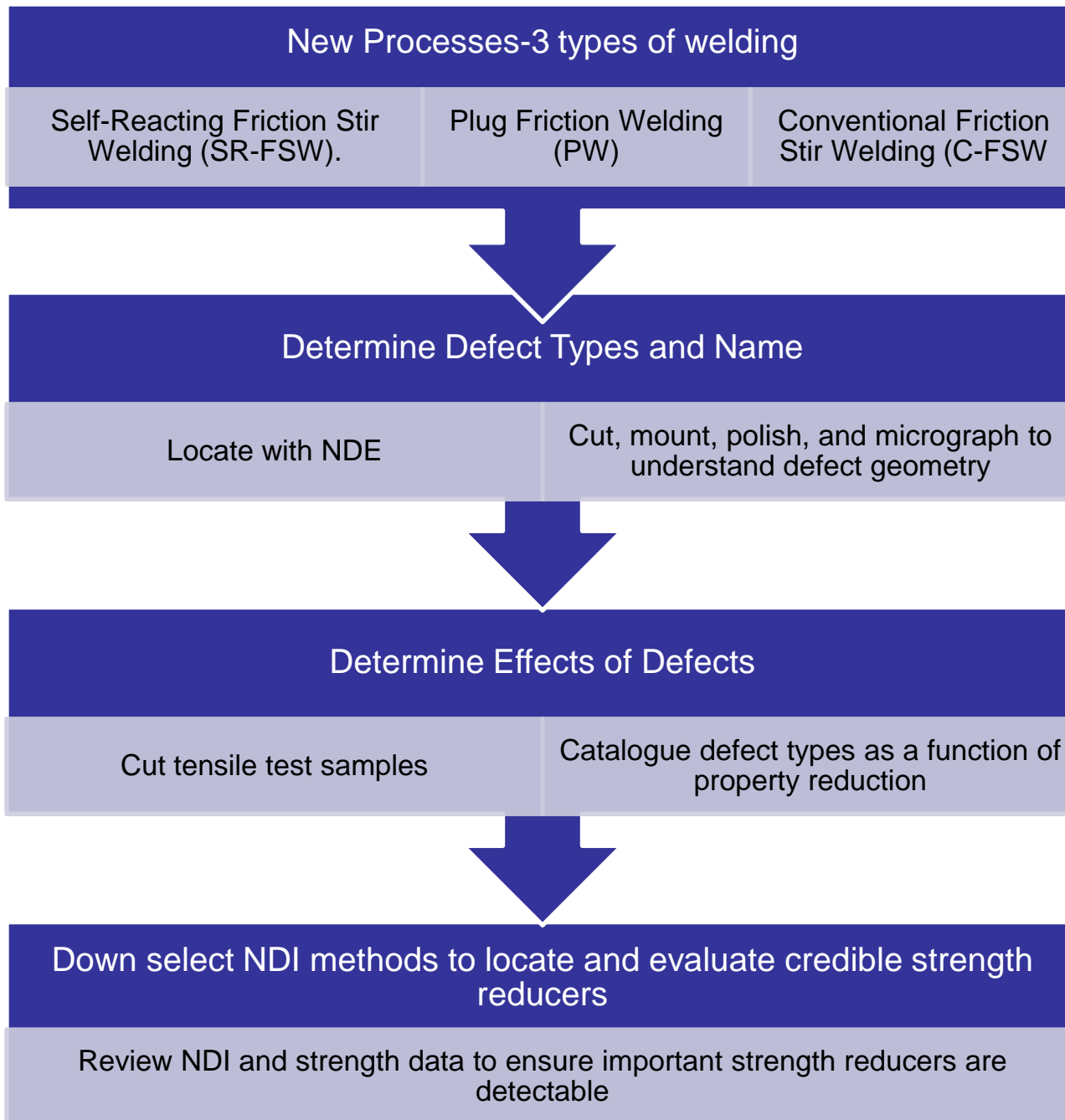
Development of Weld Inspection of the Ares I Crew Launch Vehicle Upper Stage

A detailed 3D rendering of the Ares I Crew Launch Vehicle Upper Stage. The vehicle is shown from a low-angle perspective, ascending diagonally from the bottom left towards the top right. It features a large orange cylindrical section (the External Tank) and a white conical nose cone. The nose cone is adorned with various logos, including the NASA logo and the flags of the United States, France, and the European Space Agency. The vehicle is set against a dark, textured background that resembles a night sky or a deep space environment. The overall composition is dynamic, emphasizing the scale and complexity of the spacecraft.

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Document the NDE process and freeze it by this point



Verify Defect Detection Capability

probability of detection (POD) or other demonstration process



Estimate NDE defect sizing capability.

What is the precision of the NDE measurement.

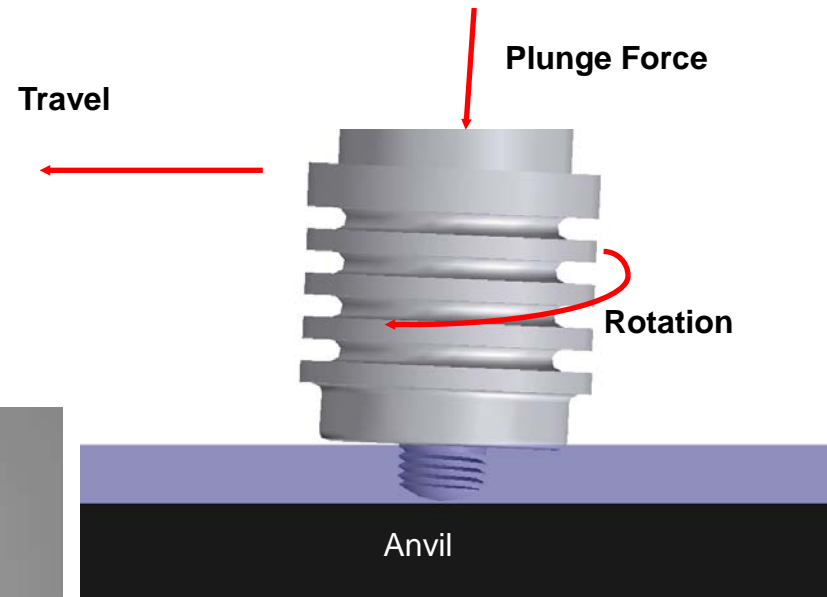
Friction Stir Welding

- Patented technology developed by The Weld Institute of Cambridge, UK
- Three types being considered for Ares I
 - Conventional
 - Self Reacting
 - Pull Plug
- Used in last few External Tanks for Shuttle Orbiter launches

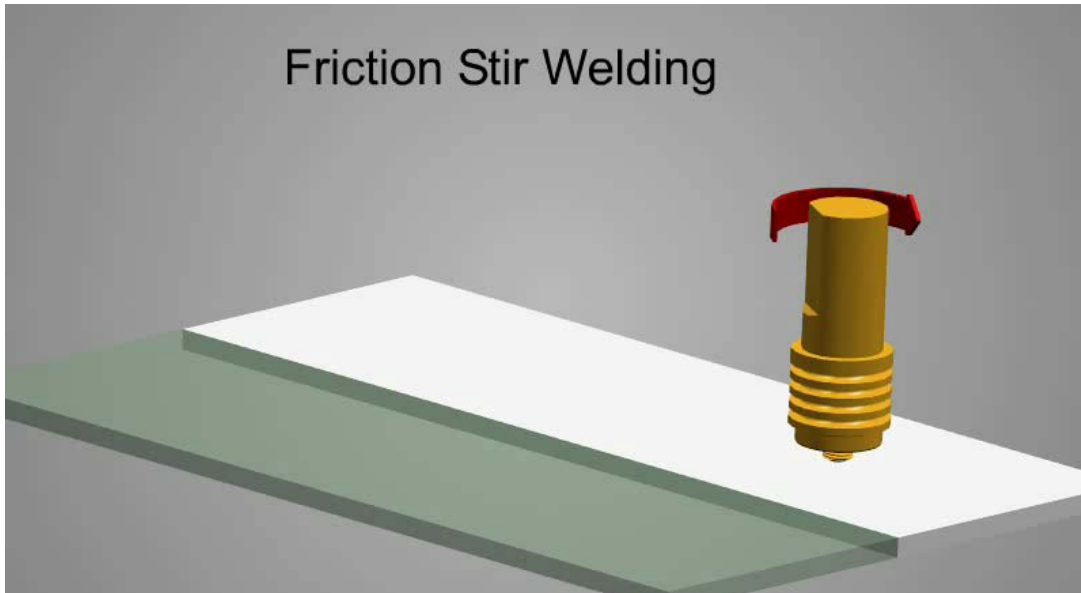
Conventional Friction Stir Welding (FSW)

Process Description

- Solid State Process
- Uses Non-Consumable Rotating Tool
- Rotating tool is plunged into work piece until the tool shoulder is in contact with the work piece. Tool then traverses along the weld joint. At end of weld joint the tool is withdrawn from the work piece.



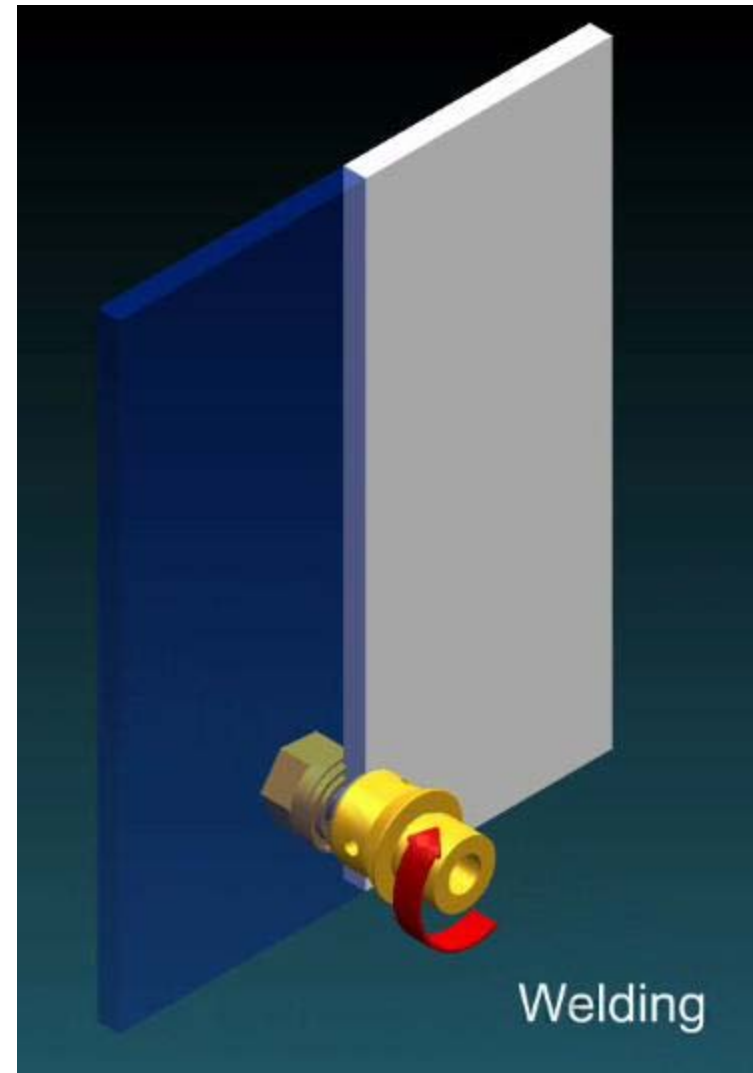
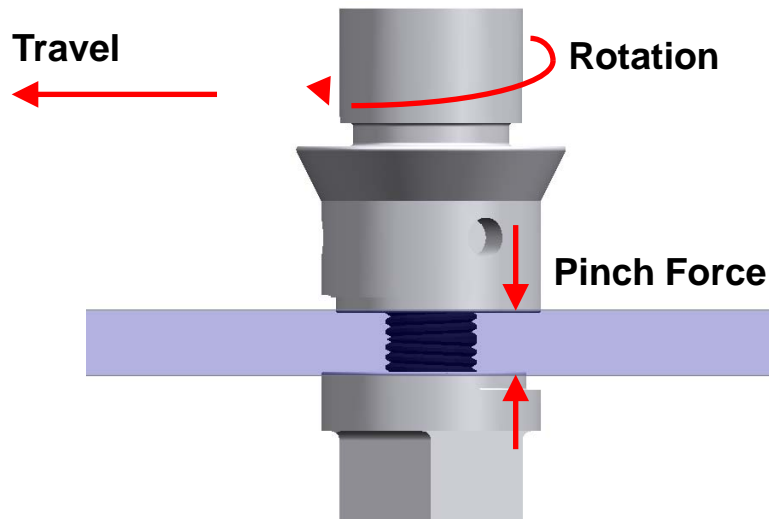
Friction Stir Welding



Self Reacting Friction Stir Welding (SR-FSW)

Process Description

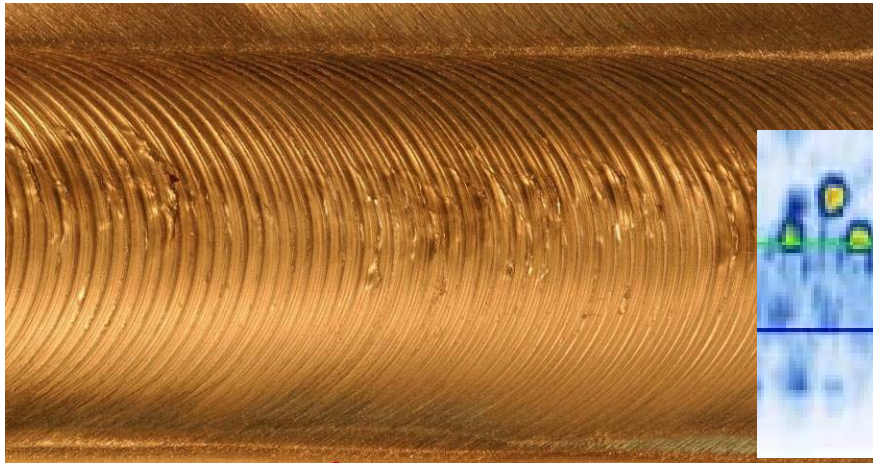
- No Anvil Required
- Rotating tool “pinches” the work piece between two shoulders and traverses along the weld joint.



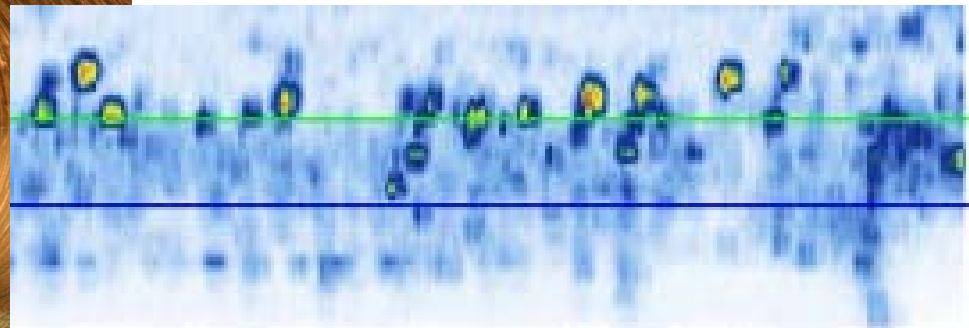
NDE for Friction Stir Welding

- Space Shuttle External Tank uses combination of x-ray, penetrant and phased array ultrasound to inspect conventional friction stir welds
- Manufacturing goal is to simplify process with single NDE method for both conventional and self-reacting friction stir welds
 - Phased array ultrasound is leading candidate for conventional and self-reacting welds
 - Radiography or eddy current may be required to detect certain defects
- Approximately 10,000 inches of welds have been inspected to date for this development effort

Galling



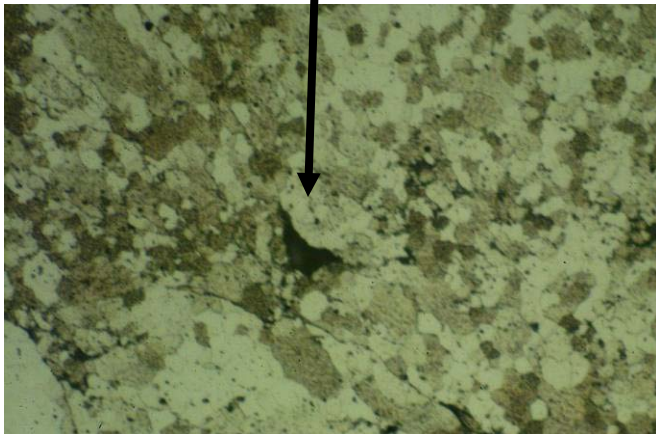
PAUT Data of Galling



Defect Examples

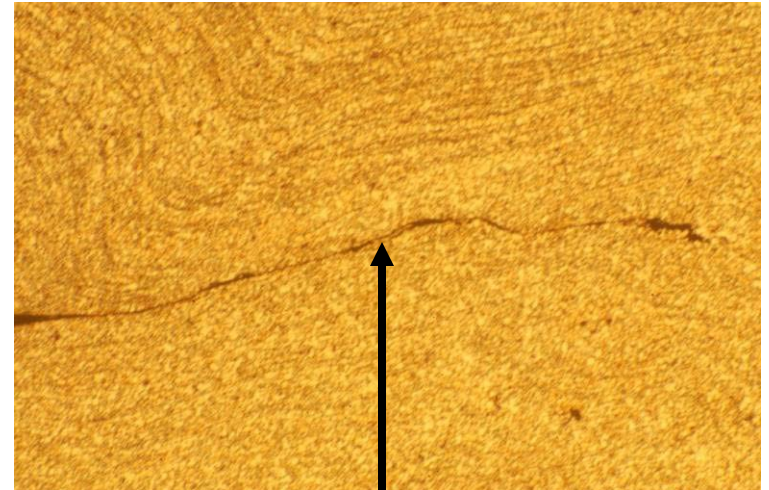


Void



400X

50X



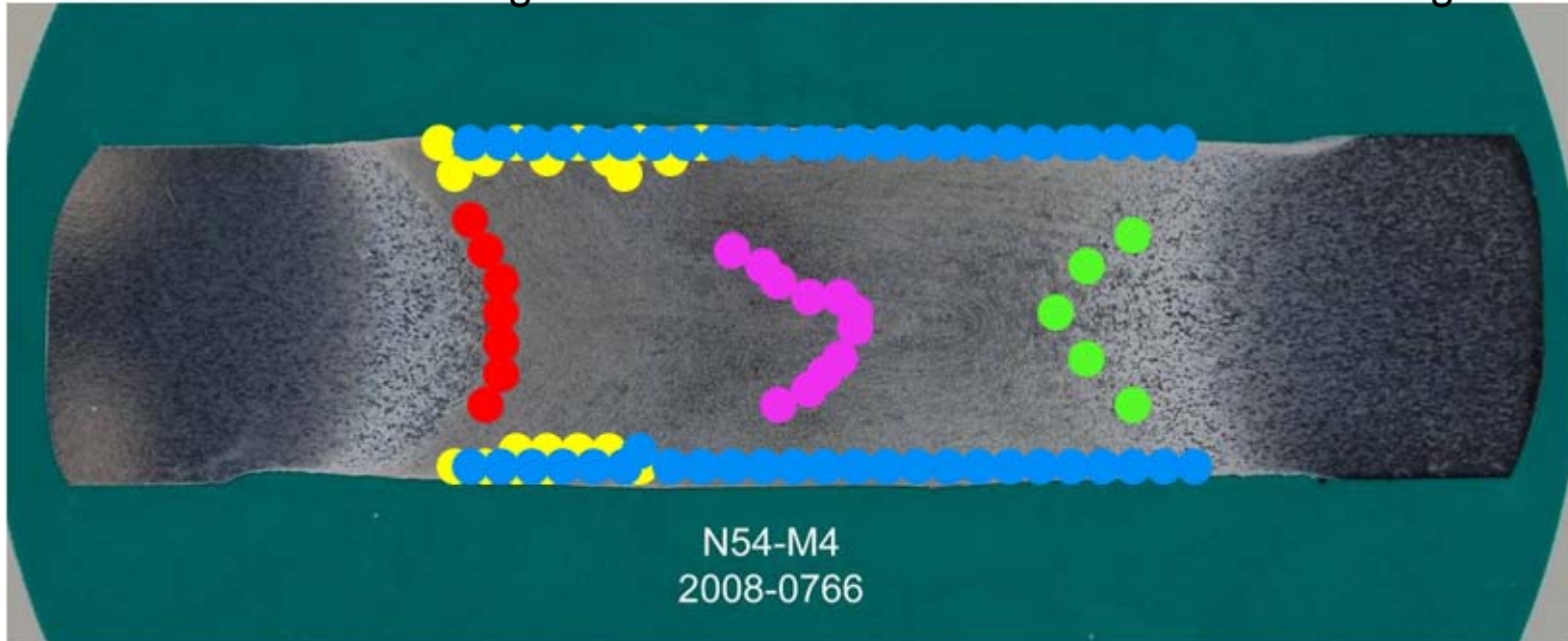
Tearing



Typical Locations of Various Defects (SR-FSW)

Advancing Side

Retreating Side

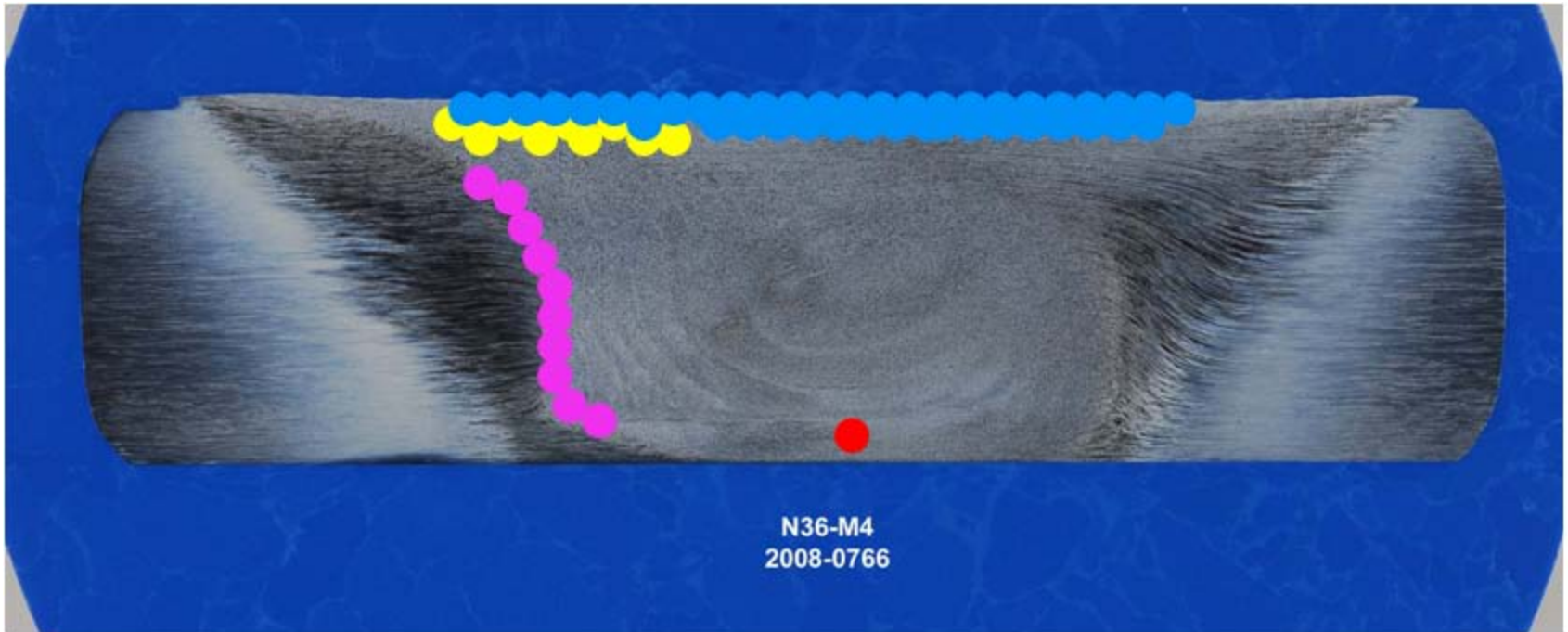


- | | |
|-------------|------------------------|
| ● Wormhole | ● Copper (bi-metallic) |
| ● Hot tears | ● Start/Stop |
| ● Galling | |

Typical Locations of Defects or Indications (C-FSW)

Advancing Side

Retreating Side



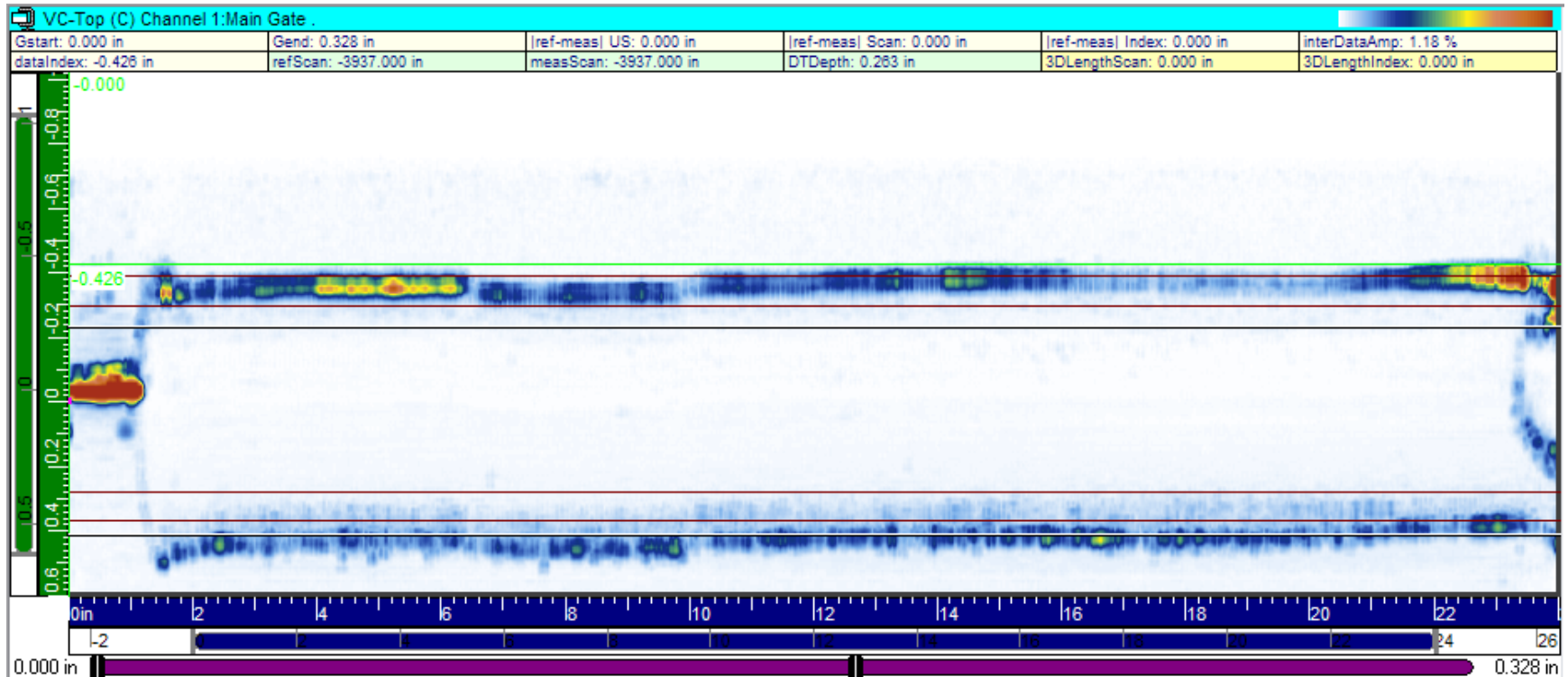
● Hot tears

● Lack-Of-Adequate Forging

● Galling

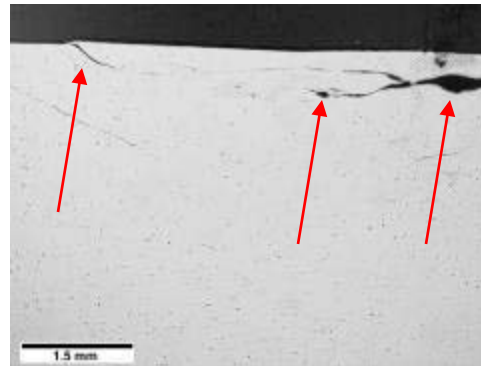
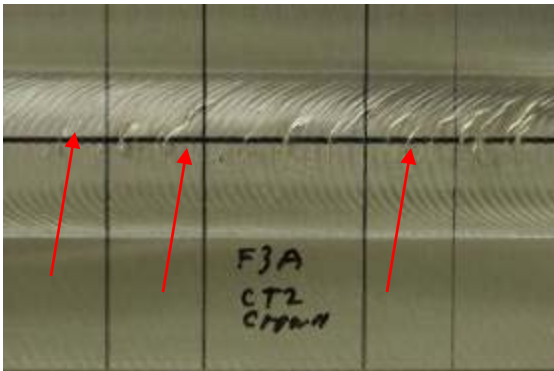
● Lack-Of-Penetration

Clean or Nominal Weld



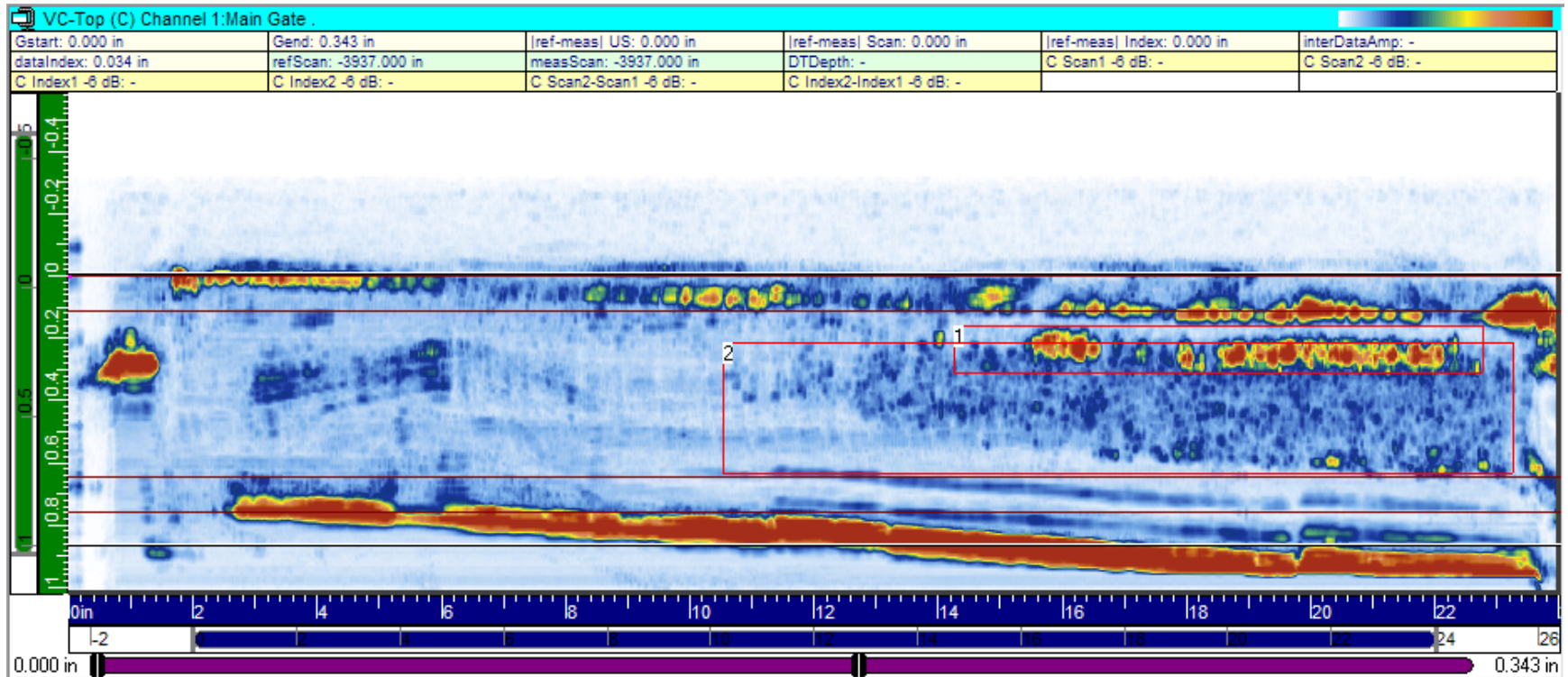
Galling/Tearing Defects

Example:

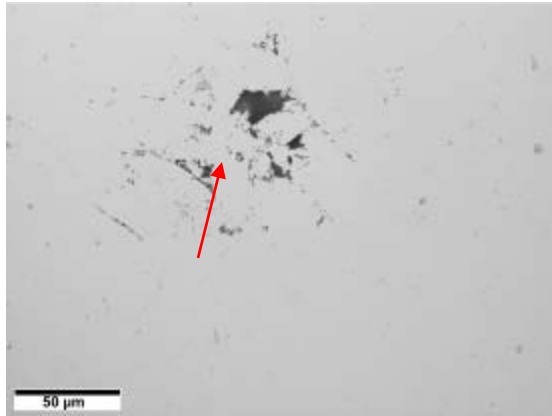


Galling – tears on the surface of the weld visually indicated by open surface features, or blisters. – curvilinear discontinuities that occur at an angle to the surface on the advancing side of the weld. Subsurface tearing has only been noted in self-reacting welds in 2195. Subsurface tearing can occur below the root or crown surface, typically follow the grain boundaries and are very tight.

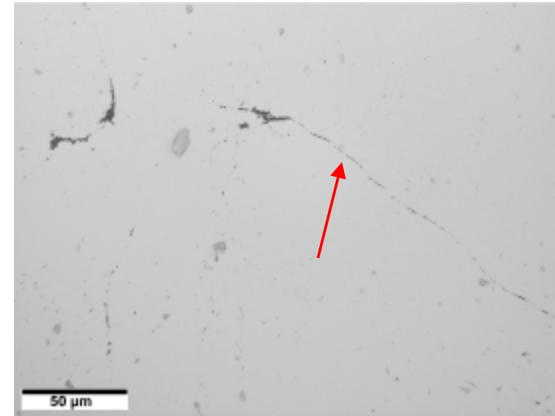
PAUT indication of Galling and Tearing at Surface



Wormhole/Voids/Lack of Adeqaute Forging



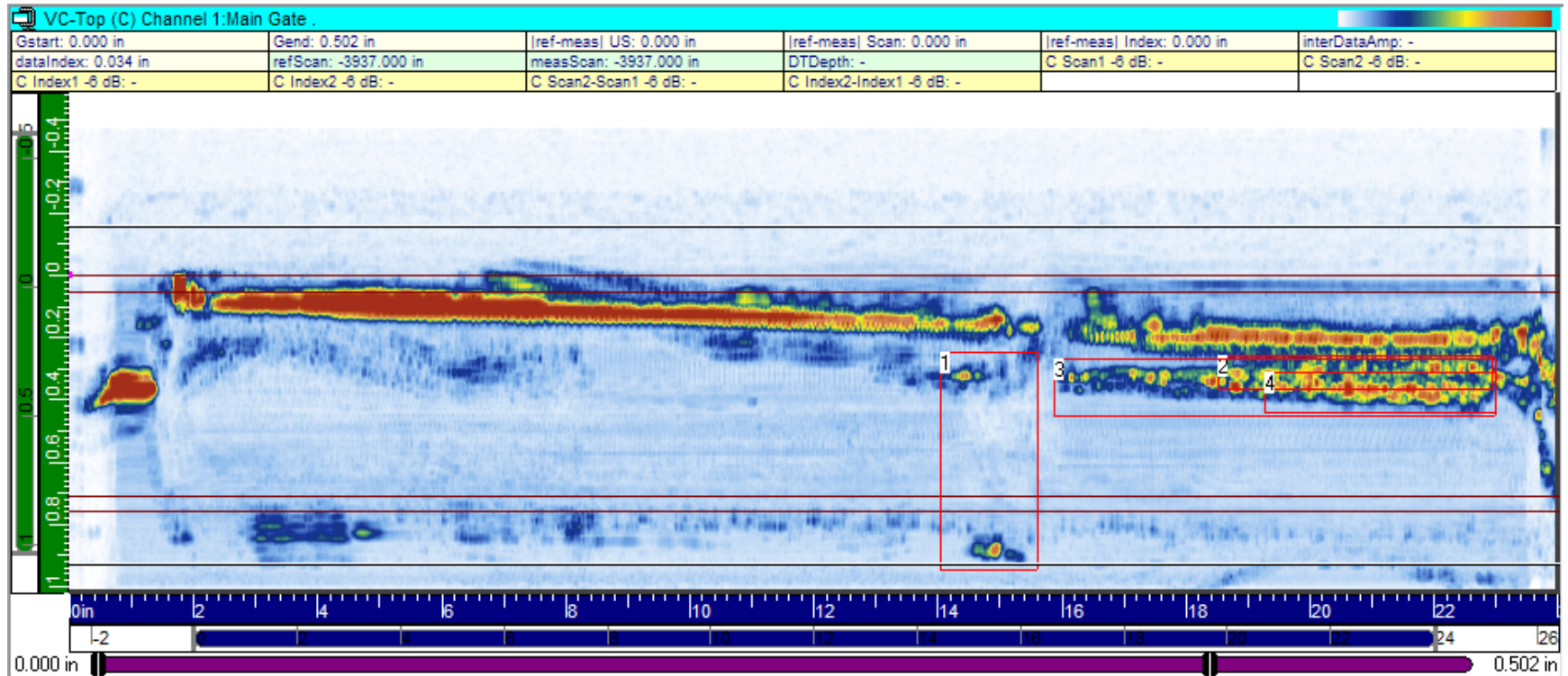
Photomicrograph showing wormhole in weld nugget



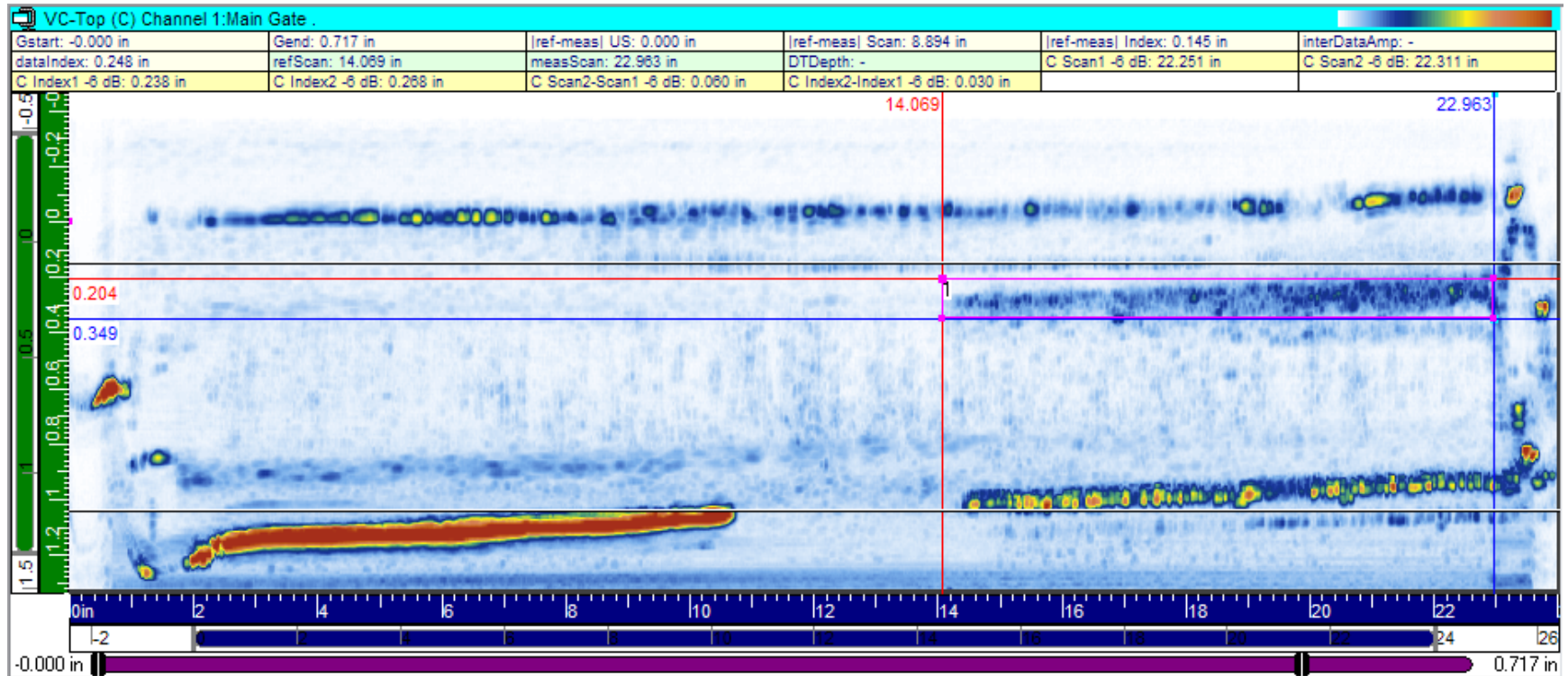
Photomicrograph that shows linear Indications in weld nugget

Wormhole/Voids/Lack of Adequate Forging – occur near mid-thickness on the advancing side close to the thermo-mechanical zone boundary and appear as voids, void clusters and linear defects. These defects may be three dimensional and traverse in the direction of the weld for some distance.

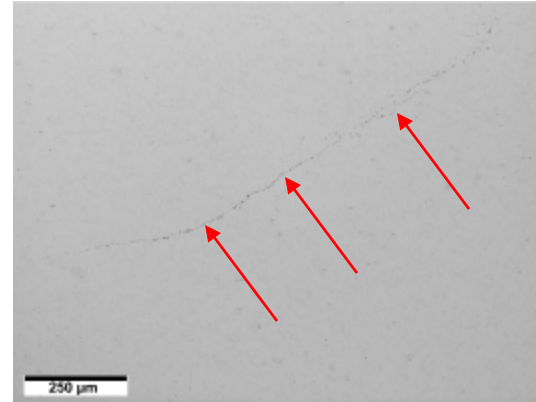
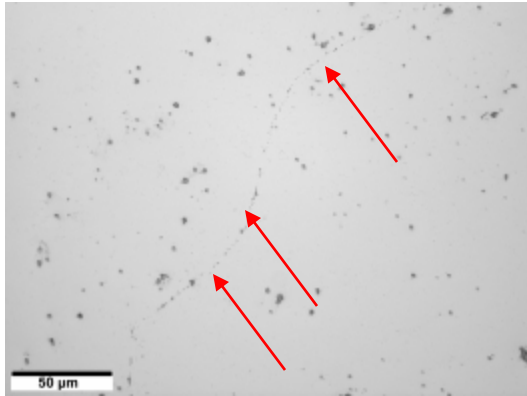
PAUT Indication of Wormhole



PAUT Indication of LAF

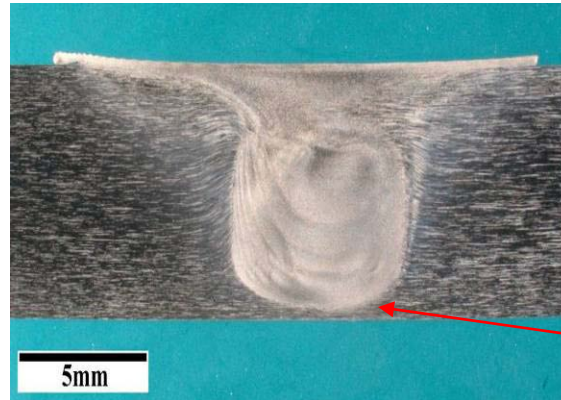
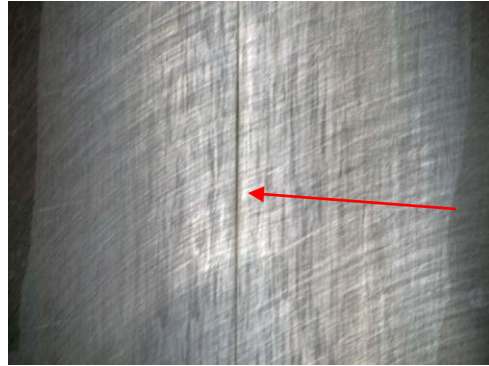


Residual Oxide Discontinuity



Residual Oxide Discontinuity - appears as a curvilinear oxide deposit running through the weld nugget. Residual oxide discontinuity (ROD) occurs in self-reacting friction stir welds.

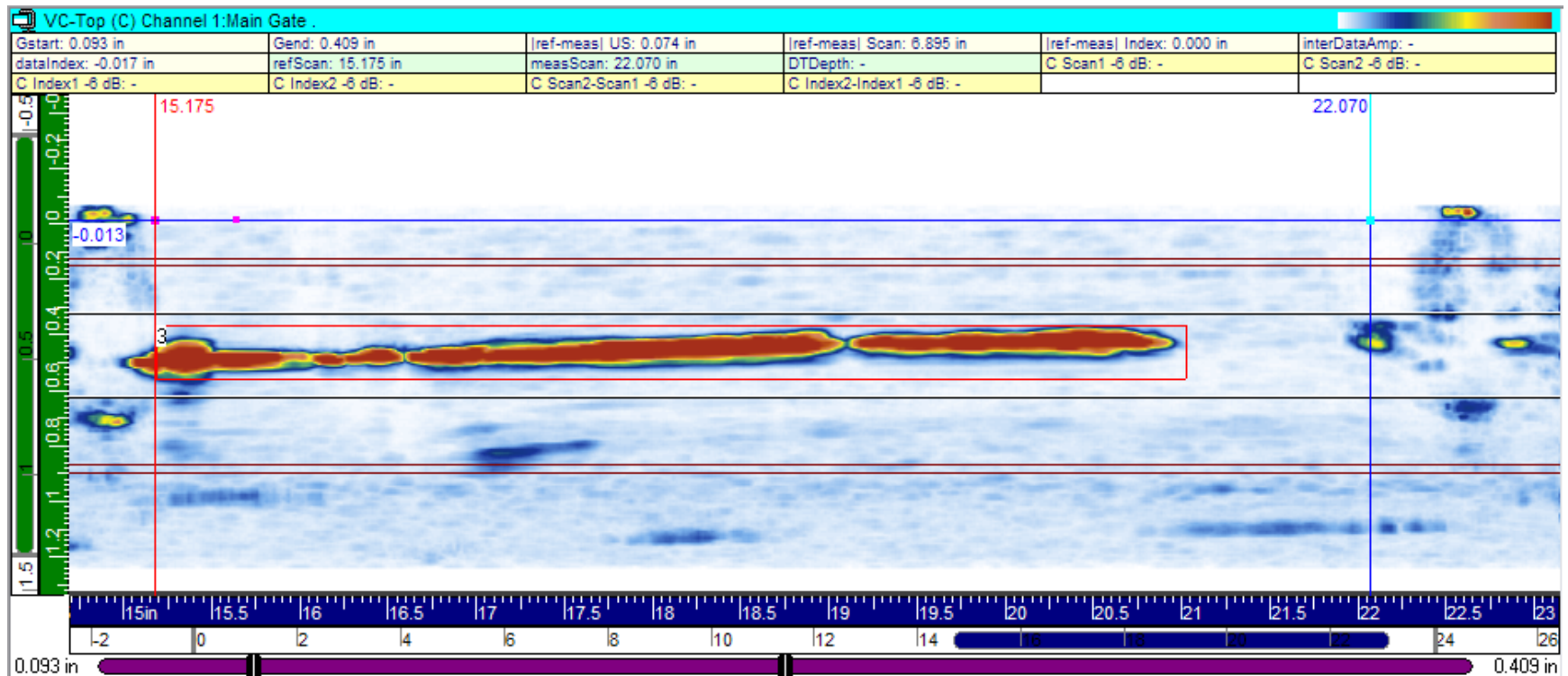
Lack of Penetration (LOP)



Lack of
Penetration in
Conventional
FSW

Lack of Penetration – an area of unconsumed weld joint, typically open to the surface, found on the root side of conventional friction stir welds

PAUT Indication of LOP



Start/Stop Indications

- Indication found in area where weld was restarted after pin tool was originally pulled out.
- Effect on strength hard to correlate
- Resembles a comma when viewed on radiograph

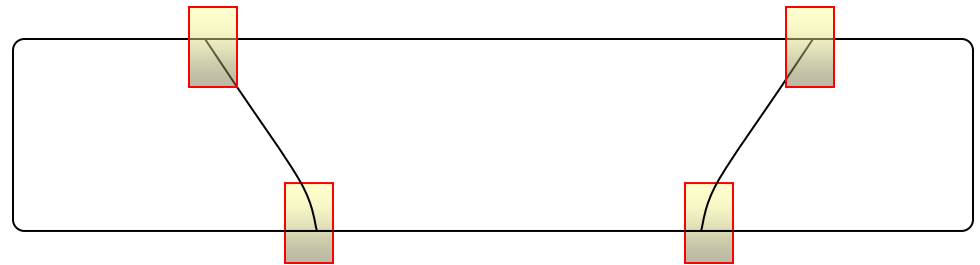
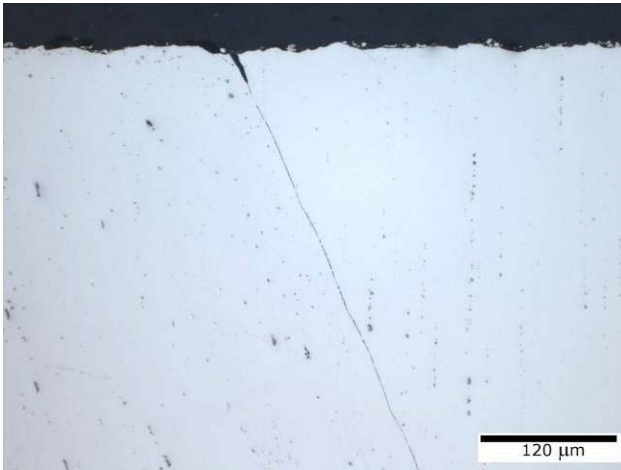
RT of Start/Stop Indication



Copper Agglomeration

- In high copper alloys copper agglomeration has been identified in macros in high Cu alloy side of weld
- These are not known to be a defect or reduce strength in weld
- Can be detected by PAUT

Plug Weld Disbonds



Typical locations of where disbonds occur in a FSW plug weld

Lack of Bonding – “kissing bond” at the interface between a friction stir plug weld and the surrounding material, usually near surface.

































Data Correlation Process

- Panels were welded at MSFC
- Inspections performed were overseen by Level III examiners and data analysis conducted
- Inspection reports generated.
- Cut plan for each panel was developed based on inspection reports
- Tensile specimens for tensile testing
- Fractures sent for fractography
- Macros sent for evaluation

Data Correlation Process

- Macro and Tensile data collected and put into tables
- Tensile data was taken 3 to 9 months after welding so some age hardening of the weld had occurred
- Individual meetings were conducted with NDE examiners to review data
- Team meetings with representatives from Metallurgy, NDE, and S&MA to review and correlate tensile, macro, and NDE data.
- Findings based on the above activities

Detection of Relevant Defects in Friction Stir Welds

Defect or Indication in Weld	VT	PT	RT	PAUT
Galling				
Tearing				
Lack of Penetration				
Wormhole/Voids/LAF				
Residual Oxide Discontinuity (Process Controlled)				
Start/Stop				
Inclusions				
Copper Agglomeration				

 Good Detection
  Limited Detection
  Poor Detection

Phased Array Inspection of Dome to Y-ring Self Reacting Weld

